Holographic Metasurface Nanolithography for Volumetric Vat Photopolymerization

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Vat photopolymerization (VPP) is an additive manufacturing (AM) or 3D printing technique that relies on the use of photo-curable resins that cure and solidify whenever light of a specific wavelength is incident upon it. VPP is generally done sequentially layer-by-layer: each layer requires light of localized intensity patterns to be projected onto it for curing before more resin is deposited for the next layer's exposure and curing. Instead of a time-consuming layer-by-layer process, we propose and investigate a volumetric, simultaneous VPP process whereby uniform laser light is irradiated through a metasurface (a.k.a. metamask) to project a hologram inside a cuvette with resin, resulting in the successful production of a demonstration part ~2 mm in size within 3 seconds. To this end, first, we parameterize the resin's time-dependent response to varying light intensities by adding into the resin an aggregation-induced emission (AIE) molecule known to fluoresce only in aggregated or solid state, irradiating the mixture, and analyzing the fluorescence output of the mixture over time. With these results, we fit a dosage-to-cure response. Second, we set up a machine learning (ML) optimization procedure that determines the metamask pixel heights that result in phase shifts of the exiting light which propagates various distances in the axial z-direction. We demonstrate this procedure for 2400 × 2400 pixels optimized for 12 z-slices. This is an overdetermined system: we discuss possible loss functions that we can use to minimize error and the results that follow. This proposed approach provides a scalable route to high-fidelity, error-minimized holographic metasurface lithography at small length scales for potential applications in the electronics industry.